ENHANCING UTILIZATION OF BUILDINGS THROUGH INTEGRATED ANALYSIS OF SPACE, USER, AND USER ACTIVITY

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ABSTRACT: Enhancing utilization of buildings is gaining in importance in response to a challenging economy; thus, there is a need for a method that analyzes space, user, and user activity in an integrated way to provide project stakeholders with utilization information to support their decision-making about buildings. Conventional methods, such as architectural programming and post-occupancy evaluation, lack a formal relationship between user activity and other information, and therefore, are coarse-grained. This relationship has been formalized by two relatively new methods that provide fine-grained utilization information: workplace planning and space-use analysis. We characterize these two methods with focuses on their usage in different phases (i.e., planning, design, occupancy), required information that needs to be gathered, and the achievement and limitations in terms of three criteria, i.e., consistency, efficiency, and transparency. This characterization would not only help project stakeholders select and use a method that best meets their purposes for enhancing utilization of their buildings, but also provide researchers with promising research topics regarding enhancing utilization of buildings.

Keywords: Utilization; User activity; User; Space; Workplace planning; Knowledge-based space-use analysis

1. INTRODUCTION

Advances in the representation of product (or Building Information Model), organization, and process models in the construction industry, in tandem with advances in the formalization of various performance analysis methods, have facilitated the use of performance-based design (PBD), where designers test multiple design options based on the performance criteria in a rapid and consistent way and refine the design to best meet their design intention [1,2]. In this context, space-use analysis takes into account space, users, and user activities to inform designers and other stakeholders about the performance of design options in terms of space-use, i.e., how much each space of a building will be used and by which users and activities the space will be used [3]. Thus, space-use has three different perspectives: space perspective that questions if there is too much space, user perspective that questions if all users can work as they expect, and activity perspective that questions if a building supports the activities an organization needs to do for its business [3]. Answering these perspectives of a design option before the realization of the building is gaining in importance because many companies or public agencies are disposing of or condensing their workspace in response to a challenging economy.

Since these perspectives of space-use are interrelated, space utilization has been developed and used as a metric of space-use that embraces different perspectives simultaneously. According to Cherry [4], for example, 100% utilization of a space implies that it is unacceptable from user and activity perspectives due to scheduling inflexibility and long queues for activities in the space, while 0% utilization of a space implies that it is unacceptable from space perspective due to building costs. Space utilization is similar to capacity utilization in the manufacturing industry, which is a ratio of the actual output to a sustainable maximum output, i.e., capacity [5]. However, while capacity utilization is targeted at the point where marginal costs equal average costs in manufacturing [5], space utilization is targeted at the point that is predetermined by a planner or an architect [3,4,6]. In this paper, we use space utilization (or utilization) as a metric of space-use.

Conventional methods that can be used in analyzing utilization, such as architectural programming [4,7] and post-occupancy evaluation [8,9], do not formalize the relationship among space, user, and user activity concepts. Architectural programming does not formalize quantitative relationships among these concepts and therefore analyzes utilization in an unclear and inconsistent way. Post-occupancy evaluation does not incorporate project specificity into space-use analysis sufficiently enough to track and update utilization throughout the project. These methods are coarse-grained in that utilization cannot be analyzed in space, user, and activity levels, and utilization is updated linearly when a design or user information is changed.

Recently developed space-use analysis methods, such as workplace planning (WOP) [6] and knowledge-based space-use analysis (KSUA) [3], formalizes relationships among space, user, and activity concepts and the overall process of analyzing space-use to increase the granularity of the analysis and to automate some steps of the analysis. WOP defines user activities and relates the information to the space program of a building to compute utilization and determine the appropriate number of the spaces based on the utilization. KSUA builds knowledge bases of project-specific users, user activities, and spaces and automatically maps activities onto spaces and computes utilization. However, these two methods have not yet been directly compared to help project stakeholders select and use a method that best meets their purposes for enhancing utilization of their buildings.

Therefore, in this paper, we characterize these two methods based on our application of these methods into three case studies. Specifically, we compare these two methods in terms of the usage in different phases (i.e., planning, design, occupancy), required information that needs to be gathered, and the achievement and limitations regarding three criteria, i.e., consistency, efficiency, and transparency. We then explain how these methods can complement each other and can be further improved in an attempt to provide researchers in the construction industry with promising research topics in space-use analysis.

2. POINTS OF DEPARTURE

We found two space-use analysis methods, workplace planning and knowledge-based space-use analysis, that attempt to incorporate user activity into the analysis to enhance the granularity of this analysis. These methods have differences regarding their goals, required information, and usage, which have not yet been explained in detail.

2.1 Workplace planning

Workplace planning (WOP) has been developed by Pennanen [6] and applied to practice by a Finnish company named Haahtela (http://www.haahtela.fi/). Based on the value generation concept of lean production theory [10], WOP attempts to reduce waste of spaces, i.e., spaces that are not needed by value-adding activities. Therefore, WOP sets target utilization for each space and determines an “appropriate” number of spaces where utilization does not exceed target utilization but is maximized. To do so, it needs the following information: the number of user groups, activities that are linked to a user group and a set of spaces, temporal load of activities (i.e., hours that an activity demands from spaces), and target utilization of spaces. When a planner provides this information to a WOP system, this system computes total load of each space, i.e., an aggregated value of temporal loads of activities that are mapped onto this space. Then the system determines the “appropriate” number of this space that makes utilization as large as possible within the boundary of target utilization. The size of this space is then determined based on the geometry of the people and objects to be placed for activities and legislation, instructions, and norms.

2.2 Knowledge-based space-use analysis

Knowledge-based space-use analysis (KSUA) has been developed by Kim et al. [3] in an attempt to support iterative design refinement by informing a planner or an architect about space-use performance based on user, activity, and space information. It provides a logical framework in which an analyzer (a practitioner who performs space-use analysis) can gather, represent, and use the knowledge about users and spaces in support of automated space-use analysis. Specifically, KSUA proposes <User><Action><Spatial requirements> tuple (i.e., <UAS> tuple) as a representation of a user activity, which can be automatically mapped onto a set of spaces when the spaces satisfy all of the spatial requirements of the activity. Based on this formalized relationship between user activities and spaces, KSUA can be conducted by following four phases: (1) building the project-specific knowledge base, (2) mapping user activities onto spaces, (3) computing utilization, and (4) visualizing the results. When an analyzer (a practitioner who performs space-use analysis) develops the knowledge base that describes user, activity, and space information in a computer-interpretable form, KSUA system then reasons about the knowledge base to automatically map activities onto spaces and compute utilization based on the mapping.

3. CASE STUDIES

To compare and characterize two space-use analysis methods that are described in the previous section, we conducted three case studies on which we hypothetically tested these methods to see how these methods would deal with the tests. The three cases are the Jerry Yang and Akiko Yamazaki Environmental and Energy (Y2E2) Building located at Stanford University, United States of America, the Cygnaeus High School located in Jyväskylä, Finland, and the H Publishing Company located in Seoul, South Korea (Table 1).

Table 1. Summary of case studies.

	Y2E2	Cygnaeus	H Publishing
The number of space types	9	6	3
The number of user groups	5	4	3
The number of user activities	13	5	4
The number of hypothetical tests	2	3	3

3.1. The Y2E2 Building, Stanford University

Kim et al. [3] apply KSUA into the select areas in the Y2E2 Building (educational building) to demonstrate its effectiveness in analyzing and visualizing utilization of this building (For detailed information, please read [3]). Based on this case study, we conducted the following two hypothetical tests:

- *T1: Changes in space configuration*

We increased the number of small conference rooms from 2 to 3 while maintaining the gross area of the building by reducing the size of a large conference room (546 ft^2 to 389 ft^2). Since WOP relies on a fixed relationship between spaces and users, which is manually constructed by a planner, it computes the utilization of each space based on the same activity-space mapping. Thus, the total load of each small conference room is reduced due to the increased number of this space, and sequentially, the utilization of this space is also decreased from 0.99 to 0.66. The utilization of other spaces remains unchanged. However, in KSUA, activities are mapped onto spaces based on their spatial requirements, and reduced size of a large conference room triggers changes in activity-space mapping. In this case study, links from two activities ("grads having class" and "undergrads having class") to the space "large conference room" are deleted because these activities require any space that is larger than 400 ft^2. This change then affects utilization of other spaces. The utilization of small conference rooms is decreased from 0.99 to 0.82.

- *T2: Changes in space usage*

In this test, we prevented undergraduate students from using small conference rooms and required them to find other conference rooms for their individual study activity while maintaining the results of previous test T1. To respond to this change, WOP requires a planner to delete all activities of undergraduate students from small conference rooms, find other conference rooms in the space list, and map these activities onto the found conference rooms. In contrast, KSUA formulates spatial requirements of each activity as the knowledge base, and therefore, an analyzer has to change spatial requirements of undergraduate students' activities. An analyzer also needs to add "undergraduate students" into the "block" property of the space "small conference room" to prevent them from using this space. Thus, although the computation of utilization is based on the same theory, WOP and KSUA map activities onto spaces in a different way.

3.2. The Cygnaeus High School

Pennanen [6] describes the Cygnaeus High School project (educational building) in Finland to demonstrate the effectiveness of WOP. This case is described also in [11] (For detailed information, please read [6,11]). Based on this case study, we conducted the following three hypothetical tests:

- *T3: Unsatisfied requirements*

This case study describes a discussion about an auditorium where the auditorium was removed due to its low utilization and three 80m^2 classrooms were planned to be utilized for the activity "final examination before graduation." To accommodate the activity, these classrooms need to have portable walls with good sound insulation. Based on this discussion, we developed a test where the good sound insulation requirements are not satisfied (or specified) during the design process. In this case, WOP does not change the utilization of any space because the mapping between activities onto spaces remains the same regardless of whether or not the requirements are fulfilled by design. In contrast, since KSUA represents spatial requirements and their relationships to the mapping, it automatically deletes the link from the "final exam" activity to "flexible classrooms" when the design does not satisfy the spatial requirements of this activity.

- *T4: Changes in user information*

In this test, we doubled the number of teachers (from 70 to 140) and saw how two methods react to this change. Given that the utilization of 70 workstations for teachers is 18% according to this case study, WOP would change the utilization from 18% to 36%, which is still fairly low according to Cherry [4] and Pennanen [6], since the total load for each workstation is doubled. However, because all 140 teachers would like to have their own workstations, this doubling in the number of teachers would result in the lack of workstations. WOP does not represent the designation of a space, and therefore, an analyzer has to explain this "real" meaning to the client on an ad hoc basis. In contrast, KSUA takes into account the designation in the analysis, and therefore, maintains the utilization of 18% and notifies the analyzer that 70 workstation are lacking (Figure 1).

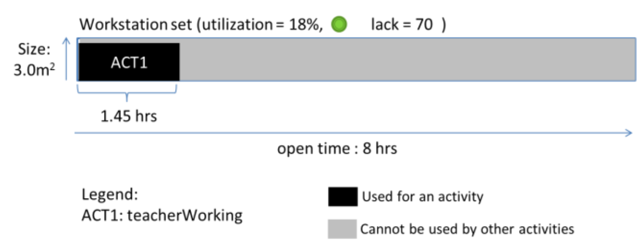

Figure 1. Activity of workstation set example in T4.

- *T5: Addition of a space type*

This case describes that the school added a club for the student association at the request of the association. We investigated how two methods deal with this addition into their systems. WOP does not automatically analyze the impact of adding the club on space-use because it depends on fixed relationships between activities and spaces. A planner must map activities that can be accommodated by the club onto this space on an ad-hoc basis. On the other hand, KSUA automatically finds activities that can be accommodated by the club (i.e., activities whose spatial requirements are satisfied by the club), such as "student meeting" and "student association meeting," and links these activities to the space.

3.3. The H Publishing Company

We examined the planning and design phase of a publishing company building (office building) in Korea. This building set 660 m^2 as its gross area for 20 employees of the company. However, after an architect developed the space program, this company wanted to refine the space program to increase the size of a storage room to hold additional books without exceeding its space budget (660 m^2). To make a decision to address this trade-off, this company needed to be informed of space-use of each space and the impact of each option on the space-use (For detailed information, please read [3,12]). Based on this case study, we conducted the following three hypothetical tests:

- *T6: Changes in space configuration*

In this test, we reduced the number of meeting rooms from 3 to 2 to increase the size of the storage room. In this case, both WOP and KSUA are able to rapidly provide consistent utilization information in response to this change. However, these methods work in a different way. WOP updates the utilization of meeting rooms immediately because it relies on the activity-space mapping that is predetermined by a planner. In KSUA, an analyzer predetermines spatial requirements of activities rather than the activity-space mapping itself. Thus, KSUA first re-evaluates the relationships between activities and spaces before computing utilization whenever it finds any modification in user, user activity, and space information.

- *T7: Changes in space usage*

There was an art room that was designated for the president of the company to use for the activity of painting. In this test, we allowed this art room to be used for activities other than the painting activity to reduce the utilization of meeting rooms. To respond to this change, WOP requires a planner to manually update the mapping because (1) the designation that was originally needed by the painting activity is not represented, (2) rules for activity-space mapping regarding the designation are not formalized, and (3) spatial requirements of other activities, such as employees' meeting and editors' editing books, are not represented. In contrast, when an analyzer changes the designation property in the spatial requirement of the painting activity, KSUA automatically updates the activity-space mapping, i.e., it adds a new link of "editors' editing books" activity to "art room" space.

- *T8: Generation of multiple options*

In space-use analysis, there is a need for generating and testing multiple options to find the best space configuration or usage solution that fits client's needs and business purposes. We generated the following three space usage options regarding where "editors' editing books" activity can be accommodated: (1) a quiet room, (2) a workstation placed in an office area, and (3) a workstation placed in any space. To test and compare these options in terms of the utilization of spaces, WOP planner must manually find spaces that satisfy the required condition and link the "editors' editing books" activity to these spaces to compute utilization for each option. However, since KSUA can generate and represent different options in explicit knowledge bases, a planner can easily and efficiently test these options simply by generating many spatial requirements and changing requirements linked to the "editors' editing books" activity. For example, using F-Logic [13], a knowledge representation and reasoning language, the three options in this test can be represented by:

Constraint1:WholeRoomUseRequirement [space -> anySpace, number -> 1, conditions -> quiet].

Constraint2:EquipmentUseRequirement [space -> officeArea, equipment -> workstation].

Constraint3:EquipmentUseRequirement [space -> anySpace, equipment -> workstation].

4. CHARACTERIZATION OF SPACE-USE ANALYSIS METHODS

This section describes the characterization of two space-use analysis methods based on eight hypothetical tests on two educational buildings and one office building, described in the previous section.

4.1 Usage of space-use analysis methods

The primary goal of WOP is to plan spaces and their requirements for accommodating expected user activities within the target utilization level. WOP is normative because it conveys the information of what spaces a client needs to have (i.e., space configuration) for his or her business operation, i.e., space usage. When a planner adds a space into WOP system, he or she must know what activities are to be performed in this space. Thus, in the planning phase, WOP can be used to generate a "one and only" space program that can accommodate all user activities that are identified and quantified by a planner. In the design phase, this space program can be used to steer an architect's design development. However, although a requirement is not satisfied in a design option, WOP maintains the same activity-space mapping that is defined by a planner, and therefore, WOP is not able to evaluate the impact of the unfulfilled requirement on utilization of a building. In the occupancy phase, a planner can use WOP to compute the utilization based on information of existing spaces and users and recommend how to renovate these spaces for accommodating user activities.

On the other hand, KSUA attempts to analyze utilization of a building based on a given user and space information. KSUA is descriptive because it conveys the information of how much each space will be used based on a set of spaces (i.e., space configuration) and users (i.e., space usage). Since KSUA has explicit and computer-interpretable knowledge about spatial requirements of each activity, it can automatically re-evaluates and modifies activity-space mapping whenever space or user information changes. Thus, in the planning phase, KSUA can be used to analyze and compare space-use of multiple space program options in support of a client's or planner's decision-making. In the design phase, it can be used to analyze space-use of multiple design options in support of a client's or an architect's decision-making. Similarly, in the occupancy phase, it can be used to analyze space-use of multiple renovation plans in support of a client's or a facility manager's decision-making.

4.2. Required information for space-use analysis methods

Both WOP and KSUA require the following information about users, their activities, and spaces.

- User: the number of each user group
- Activity: user (or driver) and the temporal load of each user activity, which can be computed using duration, frequency, and group size of an activity.
- Space: space type

In addition, WOP requires a planner to provide activity-space mapping information and target utilization of each space for computing the required number of each space by taking into account the target utilization and the total load of the space. Other design requirements of a space are determined after mapping activities onto this space [6], using geometry of users and objects, legislation, regulations, and norms that are also provided by a planner.

KSUA does not require an analyzer to provide activity-space mapping information, but requires him or her to provide spatial requirements of each activity and design features of each space, such as the number and the size of a space type, and equipment that a space type contains, for automatically mapping activities onto spaces and computing utilization.

4.3. Achievements and limitations of space-use analysis methods

This section describes achievements and limitations of WOP and KSUA in analyzing utilization of a building in terms of consistency, efficiency, and transparency.

- *Consistency*

A consistent analysis produces results that vary only slightly or not at all among different trials, and therefore, it provides opportunities for calibration in the future [14]. Generally, the consistency of an analysis can be enhanced by formalizing the analysis and making it a computer-assisted process. Conventional space-use analysis methods lack a formal model that relates space, user, and user activity information, and therefore they provide inconsistent utilization information when a planner or an architect attempts to query utilization of a specific space, user, or activity. Utilization is updated linearly when a design or user information is changed.

To enhance the consistency of space-use analysis, both WOP and KSUA provide fine-grained analysis of utilization by incorporating user activity information into their systems. WOP has been put in practice after its development, and thus, there are many cases that show the effectiveness and the applicability of WOP [6], [15]. However, since WOP relies on manual mapping of activities onto spaces by a planner, the analysis can be inconsistent among planners when there is a change in space configuration or space usage. Therefore, KSUA further enhances the consistency by representing spatial requirements of user activities and design features of spaces and letting a computer reason about them to map the activities onto "appropriate" spaces.

Although KSUA enables analyzers to perform space-use analysis consistently given a user, activity, and space information, the accuracy of KSUA has not yet been tested by gathering real occupancy and usage data. The accuracy of the analysis must be measured and improved by both calibrating the input parameters and elaborating the mapping rules that govern users' space selection mechanisms in the analysis. Time-varying and stochastic features must also be incorporated into KSUA to increase the accuracy and applicability.

- *Efficiency*

Efficiency is the ratio of the actual output to the actual input [16]. In space-use analysis, output means the utilization information, and input means the time an analyzer would spend on conducting the analysis. Automation of space-use analysis is one prominent way to increase the efficiency because there are complex relationships between user activities and spaces, along with the multiplicity of options that a planner or an architect would generate to make a decision, each of which has a variety of spaces.

Although WOP contributes to the efficiency of space-use analysis by formalizing and automating the utilization computation process, the activity-space mapping process still remains to be conducted manually, and thus time consuming. Whenever there is a change in space configuration or space usage, an analyzer must investigate the impact of this change and update the mapping prior to the analysis. This limitation becomes clear when an analyzer generates and compares multiple options: the analyzer must manually map all user activities onto spaces for each option. To overcome this limitation regarding the efficiency, KSUA automates this mapping process to enable rapid update of the mapping and easy testing of different options.

- *Transparency*

Transparency is defined as the ability of a production process or its parts to communicate with people [17]. Lack of transparency in an analysis increases the rate of errors, which is not visible to stakeholders, and diminishes motivation for continuous improvement [18].

One way of improving transparency is rendering invisible attributes visible through measurements [17]. Because WOP lacks this visual control in the process of reporting the utilization of a building, Pennanen [6] notes in his paper that 'sometimes clients would have preferred to work visually and they found that numbers (utilization) were difficult to work with and base decisions on.' To overcome this limitation, KSUA offers ways of visualizing the results, such as diagrams for activity-space mapping and activity-loaded space [3]. Different transparency levels for different stakeholders can be further investigated and applied in KSUA.

5. CONCLUSTION

Conventional space-use analysis methods, such as architectural programming and post-occupancy evaluation, lack a formal relationship between user activity and other information, and therefore, are coarse-grained, i.e., utilization cannot be analyzed in space, user, and activity levels, and utilization is updated linearly when a design or user information is changed. This relationship has been formalized by two relatively new methods that provide fine-grained utilization information: workplace planning and space-use analysis. However, these two methods have not yet been directly compared to help project stakeholders select and use a method that best meets their purposes for enhancing utilization of their buildings.

Therefore, we characterized these two space-use analysis methods to help project stakeholders select and use a method that best meets their purposes for enhancing utilization of their buildings. We first conducted three case studies (two educational buildings and one office building) on which we hypothetically tested these methods to see how these methods would deal with these tests. Based on the case studies, we characterized these methods with focuses on their usage in different phases, required information that needs to be gathered, and the achievement and limitations in terms of the following three criteria: consistency, efficiency, and transparency. This characterization also provides researchers with promising research topics regarding enhancing utilization of buildings. To achieve the full potential of our work, however, these two methods must be tested on more cases and compared using quantitative metrics to provide more rigorous evidence regarding the power and the generality.

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